Microbial biomass in subtropical forest soils: effect of conversion of natural secondary broad-leaved forest to *Cunninghamia lanceolata* plantation

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Abstract: Conversion of natural secondary broad-leaved forest to *Cunninghamia lanceolata* plantation is a common management practice in subtropical China. In this study, we compared soil physico-chemical properties, microbial biomass in one natural secondary broad-leaved forest and two *C. lanceolata* plantation sites to estimate the effects of forest conversion on soil microbial biomass at the Huitong Experimental Station of Forestry Ecology, Chinese Academy of Sciences. Concentrations of soil organic carbon, total nitrogen, NH_4^+-N and microbial biomass carbon and nitrogen were much lower under *C. lanceolata* plantations as compared to natural secondary broad-leaved forest. Soil microbial biomass C in the first and second rotation of *C. lanceolata* plantations was only 53%, 46% of that in natural secondary broad-leaved forest, and microbial biomass N was 97% and 79%, respectively. The contribution of microbial biomass C to soil organic C was also lower in the plantation sites. However, the contribution of microbial N to total nitrogen and NH_4^+-N was greater in the *C. lanceolata* plantation sites. Therefore, conversion of natural secondary broad-leaved forest to *C. lanceolata* plantation and continuous planting of *C. lanceolata* led to the decline in soil microbial biomass and the degradation of forest soil in subtropical China.

Keywords: Soil microbial biomass; *Cunninghamia lanceolata* plantation; Natural secondary broad-leaved forest; Forest conversion
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Introduction

With an increasing demand for timber production, natural secondary broad-leaved forest was gradually replaced by *Cunninghamia lanceolata* which is a fast-growing species tree in southern China; and more than 1.21×10^7 hm^2 are planted at present, accounting for one-quarter of the total plantation area in southern China (Chen and Wang 2004). The conversion of natural secondary broad-leaved forest to *C. lanceolata* adversely affects soil physico-chemical characteristics (Ding and Chen 1995; Wang *et al*. 2005a, b). In addition, continuous cropping of *C. lanceolata* has resulted in soil degradation and productivity decline (Chen *et al*., 1990). However, it is difficult to detect these changes in soil physico-chemical properties. Soil microbial biomass, the most active fraction of soil organic matter, plays an important role in nutrient retention and soil fertility in terrestrial ecosystems, although it presents a relatively small standing stock of nutrients compared to soil organic matter (Smith and Paul 1990). Soil microbial biomass is more likely affected by changes of land use or forest conversion, compared to the total soil organic carbon. Therefore, some researchers had suggested that soil microbial biomass can be used as a more useful parameter for assessing soil quality than total soil organic matter and as an early sensitive indicator of change in soil organic matter status (Bremer *et al*. 1994; Gregorich *et al*. 1994; Chilima *et al*. 2002; Li *et al*. 2004). Therefore, one of the methods to assess the pace and progress of soil restoration is through the monitoring of soil microbiological properties and particularly soil microbial biomass.

The objective of the research is to compare soil microbial biomass in the natural secondary broad-leaved forest, the first and the second rotation of *C. lanceolata* plantations and to estimate the effects of forest conversion on soil microbial biomass in subtropical China.

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Materials and methods

Site description

The study was conducted at the Huitong Experimental Station of Forestry Ecology, Chinese Academy of Sciences (26°48′N, 109°30′E) in Hunan Province, China. The mean annual temperature is 16.5°C and the annual precipitation ranges from 1200 to 1400 mm. According to Chinese Soil Taxonomy, oxisol is the principal soil type, dominantly developed from the parent rocks of slate and shale. The native vegetation is the typically subtropical evergreen broad-leaved forest, mainly composed of *Castanopsis and Lithocarpus*. However, *C. lanceolata* plantations or masson pine forests have become the major current forest communities because the natural secondary broad-leaved forest has almost been destructed by human activities. In this study, one natural secondary broad-leaved forest and two pure *C. lanceolata* plantations were selected.

Soil sampling and analysis

Ten random soil cores were collected at a depth of 10 cm to form one composite sample from the natural secondary broad-leaved forest, the first rotation and the second rotation of *C. lanceolata* plantation using a 45-mm diameter tube sampler, respectively. Three independent replicates were taken at each site. Visible roots and organic residues were removed at the time of sampling. Each sample was divided into two parts. One was

stored at 4°C until analysis for microbial biomass C and N. The other part of soil was air-dried, and then was ground for determination of soil organic C, total nitrogen, NH_4^+-N, pH value. Microbial biomass was estimated using the fumigation-extraction method (Vance *et al*. 1987). C and N contents, extracted with 0.5 M K_2SO_4 from the fumigated and unfumigated soils, were determined by the High TOC II ＋N analyzer. Microbial biomass C and N was calculated as the difference between fumigated and unfumigated as samples divided by the K_2SO_4 extract efficiency factor for microbial C and N (K_{EC}=0.45, Wu *et al*. 1990; K_{EN}=0.45, Brookes *et al*. 1985a). Soil organic C was measured with a total carbon analyzer (High TOC II ＋N, Elementar) and total N was determined by semi-micro Kjeldahl digestion (Bremner and Mulvaney, 1982). Determination of NH_4^+-N in the digests was based on the phenol-hypochlorite reaction. Bulk density by soil core method. Values were reported on a 105 °C dry matter basis.

Results

Soil physico-chemical properties

Soil physico-chemical characteristic data of the natural secondary broad-leaved forest, the first rotation and second rotation of *C. lanceolata* plantations are presented in Table 1. Soil bulk density in pure *C. lanceolata* plantations was slightly, not significantly higher as compared to natural secondary broad-leaved forest. Among the three sites, maximum soil bulk density was noticed in the second rotation of *C. lanceolata* plantation (rang 1.20–1.27 g·cm^{-3}, mean 1.24 g·cm^{-3}) and minimum soil bulk density in the natural secondary broad-leaved forest (rang 1.02–1.10 g·cm^{-3}, mean 1.05 g·cm^{-3}). Soil organic carbon content of the second rotation (mean 24.7 g·kg^{-1}) was comparatively lower than that of the natural secondary broad-leaved forest (mean 39.2 g·kg^{-1}) and the first rotation (mean 37.8 g· kg^{-1}). Contents of the total soil nitrogen and NH_4^+-N were also observed comparatively least in the second rotation and greatest in the natural secondary broad-leaved forest. The soil C: N ratio ranged from 15 to 19 with the maximum value in the first rotation and the minimum value in the natural secondary broad-leaved forest.

Table 1. Physico-chemical properties of the soils used summarized with means ± standard deviations (in parentheses)

parameters	Broad-leaved forest	First rotation	Second rotation
Soil organic C (g·kg^{-1})	39.2 ± 3.6	37.8 ± 4.2	24.7 ± 0.1
Total N (g·kg^{-1})	2.7 ± 0.8	2.0 ± 0.4	1.6 ± 0.2
NH_4^+-N (mg·kg^{-1})	17.0 ± 1.8	12.2 ± 4.3	8.4 ± 1.9
C:N	15 ± 3	19 ± 3	16 ± 2
Bulk density (g·cm^{-3})	1.05 ± 0.10 ·	1.19 ± 0.09	1.24 ± 0.07

Soil microbial biomass

Soil microbial biomass C and N in the three forest stands were illustrated in Fig. 1 and Fig. 2, respectively. Soil microbial biomass C significantly differed over the three sampling forests with the highest means of C (801 mg·kg^{-1}) in the natural secondary broad-leaved forest and the lowest means of C (371 mg·kg^{-1}) in the second rotation. The ranges of soil microbial biomass N under the natural secondary broad-leaved forest, the first and the second rotation of *C. lanceolata* plantations were 76–93 mg·kg^{-1}, 79–84 mg·kg^{-1}, and 62–74 mg·kg^{-1}, respectively. The differences in soil microbial biomass N between natural secondary broad-leaved forest and the second rotation and between the first rotation and the second rotation reached significant level (p < 0.05), but no significant difference between the natural secondary broad-leaved forest and the first rotation was found.

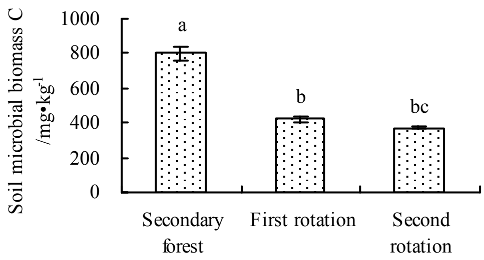

Fig. 1 Content of soil microbial biomass C under different forests. Dissimilar letters on the tops of the bars indicate significant difference at p < 0.01.

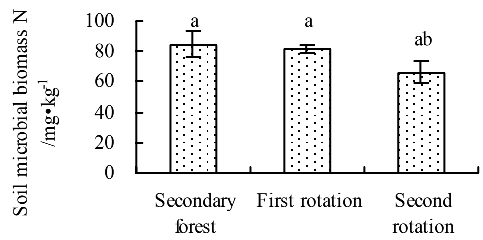

Fig. 2 Content of soil microbial biomass N under different forests. Dissimilar letters on the tops of the bars indicate significant difference at p < 0.01.

The contribution of soil microbial biomass C to total organic C was 2.0% in the natural secondary broad-leaved forest, 1.1% in the first rotation and 1.5% in the second of *C. lanceolata* plantation, respectively (Table 2). The percentage contribution of microbial biomass N to total N ranged from 3.2 to 4.2 in the three forest soils. The minimum contribution of microbial N to total N was observed in the natural secondary broad-leaved forest and maximum contribution in the natural secondary broad-leaved forest.

Table 2. Microbial biomass C and N as percentage of soil organic or total N summarized with means

parameters	Broad-leaved forest	First rotation	Second rotation
Microbial biomass C: soil organic C	2.0 ± 0.1	1.1 ± 0.1	1.5 ± 0.1
Microbial biomass N: total N	3.2 ± 0.6	4.1 ± 0.8	4.2 ± 0.3
Microbial biomass C: N	9.5 ± 0.4	5.2 ± 0.3	5.6 ± 0.6

For the three forest sites in this study, correlation coefficients of microbial biomass C and N with total organic C, total N and NH_4^+-N are listed in Table 3. The microbial biomass C showed a significant positive correlation with soil organic C (p < 0.01) in the natural secondary broad-leaved forest and the second rotation of *C. lanceolata* plantation, and with NH_{4+}-N (p < 0.01) in the three forests. The significant positive correlation of microbial biomass C with total N (p < 0.01) was only observed in the first rotation plantation. Microbial biomass N exhibited a significant positive correlation with total N (p < 0.01) in the three forests, with soil organic C (p < 0.01) in the natural secondary-

broad-leaved forest and the second rotation of *C. lanceolata* plantation, and with NH_4^+-N ($p < 0.01$) in natural secondary broad-leaved forest and the first rotation plantation.

Table 3. Correlation coefficients of soil microbial biomass, C_{mic}/C_{org} and N_{mic}/N_{tot} with Total organic C, Total N and NH^{4+}-N for three soils under different forest

	Parameters	Soil organic C	Total N	NH_4^+-N
Broad-leaved forest	Microbial biomass C	0.962**	0.856	0.961**
	Microbial biomass N	0.993**	0.926*	0.993**
First rotation	Microbial biomass C	0.791	0.988**	0.993**
	Microbial biomass N	0.822	0.995**	0.985**
Second rotation	Microbial biomass C	0.910*	0.742	0.986**
	Microbial biomass N	0.951*	0.998**	0.840

Note: *, ** Statistically significant at the 95% and 99% level, respectively.

Discussion

Soils of the natural secondary broad-leaved forest and *C. lanceolata* plantations in bulk density did not exhibit any difference. Sun *et al*. (2003) had reported that soil bulk density of the stands of *C. lanceolata* increased with the successive plantation. The results had confirmed that forest conversion of natural secondary broad-leaved forest to pure *C. lanceolata* plantation increased soil bulk density. Soil bulk density affects root and seedling growth and consequently forest productivity. This may be one of the reasons for poor undergrowth of herbaceous plants under *C. lanceolata* plantation and decline of timber productivity. Relatively poor organic carbon, total nitrogen and NH_4^+-N level in the *C. lanceolata* plantation sites agree with the other results of Wang *et al*. (2000) and Wang *et al*. (2005a, b). Level of organic carbon relates to the soil structural stability (Haynes *et al*. 1991), and hence, the low level of organic carbon reflects relatively poor soil structural stability in *C. lanceolata* plantation sites. Consequently, this would increase the potential of soil erosion and loss of soil nutrients from the plantation sites.

Comparatively low soil microbial biomass C and N in the first and the second rotation of *C. lanceolata* plantation indicated poor microbial growth in *C. lanceolata* plantation soil (Fig.1 and Fig.2). Natural secondary broad-leaved forest with the more extensive rooting systems and protective canopies may have made the soil environment more favorable for microbial growth compared to plantation due to lower soil specific gravity and higher nutrient levels, especially nitrogen. Poor microbial biomass growth and activity under *C. lanceolata* plantation could also have been due to the toxic impact of harmful allelochemical compounds released from the *C. lanceolata* leaf litter and root (Huang *et al*. 2000, 2002). In a comparative study of *C. lanceolata* plantation and Chinese sassafras soils, Jiang *et al*. (1995) observed lower microbial population under *C. lanceolata* plantation soil. It is well known that the decompsosed speed of *C. lanceolata* litter is slower than that of hardwoods because *C. lanceolata* litter has higher ratio of C: N (Liao *et al*., 2000). Microorganisms play an important role in decomposing litter. Some researchers had also reported that slow rate of decomposition of *C. lanceolata* litter may be due to poor association of decomposing microflora (Han *et al*. 2000). Meillo *et al*. (1982) suggested that microbial decomposition of leaf litter should increase with increasing N availability to microbes. In this study, the results showed that the total nitrogen and NH_4^+-N were higher in the natural secondary broad-leaved forest than in *C. lanceolata* plantations (Table 1). One reason of poor microbial biomass is that the quantity and quality of *C. lanceolata* litter is poorer and consequently results in lack of nutrients and energy which microorganisms employ.

The contribution of microbial biomass C to soil organic carbon and microbial N to total nitrogen reflects the quantum of carbon and nitrogen immobilized into the microbial standing crop (Basu *et al*. 1992) and the availability of soil organic matter to the soil microflora (Anderson and Domsch, 1986). A decrease in microbial biomass would be followed by a release of nutrients, while an increase in microbial biomass would result in an immobilization of nutrients. In this study, the contribution of microbial C to soil organic C in natural secondary broad-leaved forest was higher than in *C. lanceolata* plantations (Table 2). This result agrees with the observations reported by Xu and Xu (2003), and was very low compared to the values reported from subtropics forest soils (Huang *et al*. 2004), tropical forest soils (Dinesh *et al*. 2003; Salamanca *et al*. 2006). The contribution of microbial N to total N also had significant difference between natural secondary broad-leaved forest and *C. lanceolata* plantations, which falls within the reported range of forest soils (Martikainen and Palojarvi 1990) and agricultural soil) (Brookes *et al*. 1985b), but was much higher than the observation reported by Dinesh *et al*. (2003) and Devi and Yadava (2006) for tropical forest soils. Therefore, comparatively low ratio of microbial biomass C to soil organic C in *C. lanceolata* plantation can attribute to inhibition of microbial immobilization.

Variation of microbial biomass C: N ratio indicated that microbial biomass changed in a way due to the change in composition of soil microflora. A wider ratio usually suggests a high proportion of fungi compared to bacteria, which C: N ratio of fungi is in the range 7–12 and that bacteria often range from 3 to 6 (Anderson and Domsch 1980). In this study, the ratio of microbial biomass C: N in the natural secondary broad-leaved forest was higher than that in *C. lanceolata* plantations in soil (Table 2). In the natural secondary broad-leaved forest, fungi usually dominated, but in the *C. lanceolata* plantation soil, the amount of fungi would decrease (Hu *et al*. 2005).

Microbial biomass depends on inputs of organic carbon and also may be limited by the content and availability of N or P (Wardle 1992; Gallardo and Schlesinger 1994). The significant relationships of microbial biomass with total nitrogen and NH_4^+-N were observed in the three forest types (Table 3). Thus, an enhancement of N supply may first increase plant growth as well as roots and residues. However, no significant correlations of microbial biomass with total organic C were found in the first rotation of plantation site.

Conclusion

Forest conversion affected soil microbial biomass through changes in vegetation types and management practices. The conversion of natural secondary broad-leaved forest into pure *C. lanceolata* plantation reduced the contents of soil organic C, total N, NH_4^+-N, microbial biomass C and N. The contribution of microbial biomass C to soil organic C was also lower in the plantation sites. However, the contribution of microbial N to total nitrogen and NH_4^+-N was greater in the *C. lanceolata* plantation

sites. In addition, microbial biomass C and N were strong correlated to soil organic C, total N and NH_4^+-N. Soil microbial biomass has been widely used as a sensitive indicator to assess soil quality. Thus, Transformation of natural secondary broad-leaved forest to *C. lanceolata* plantation and continuous planting of *C. lanceolata* led to the decline in soil microbial biomass and the degradation of forest soil in subtropical China.

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